# Assessment of the Holden-impact hypothesis for Eberswalde's large delta, and tests with MSL

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$$R_{\mathrm{Ebers}} \sim \frac{1}{L_{\mathrm{melt}}} \Delta T_{\mathrm{b}} h_{\mathrm{b}} \frac{\rho_{\mathrm{b}}}{\rho_{\mathrm{w}}} C_{\mathrm{b}}$$

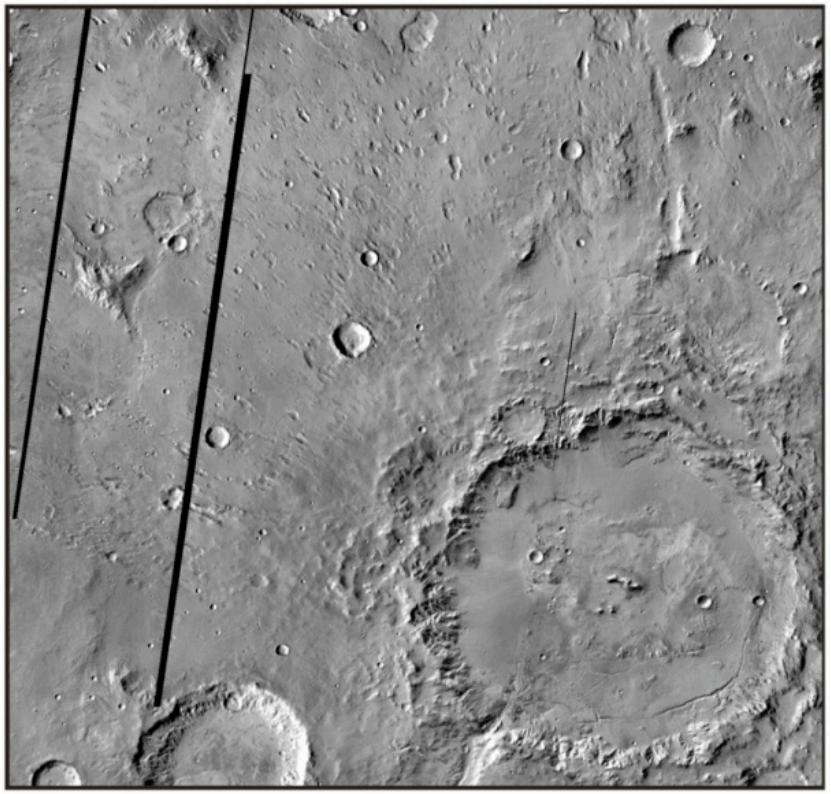
**Impact scaling: ~ $10^2$m** **Inference from data: $10^{1\text{-}2}$ m**

$$\Delta t_{\mathrm{Ebers}} \sim \frac{1}{\kappa} \left( \frac{h_{ej}}{2.32} \right)^2$$

**Impact scaling: ~$10^3$ yr** **Inference from data: > $10^{3\text{-}4}$ yr**

This talk benefited from discussions within the fluvial processes tiger team

# Did the Holden impact cause the formation of Eberswalde's delta?



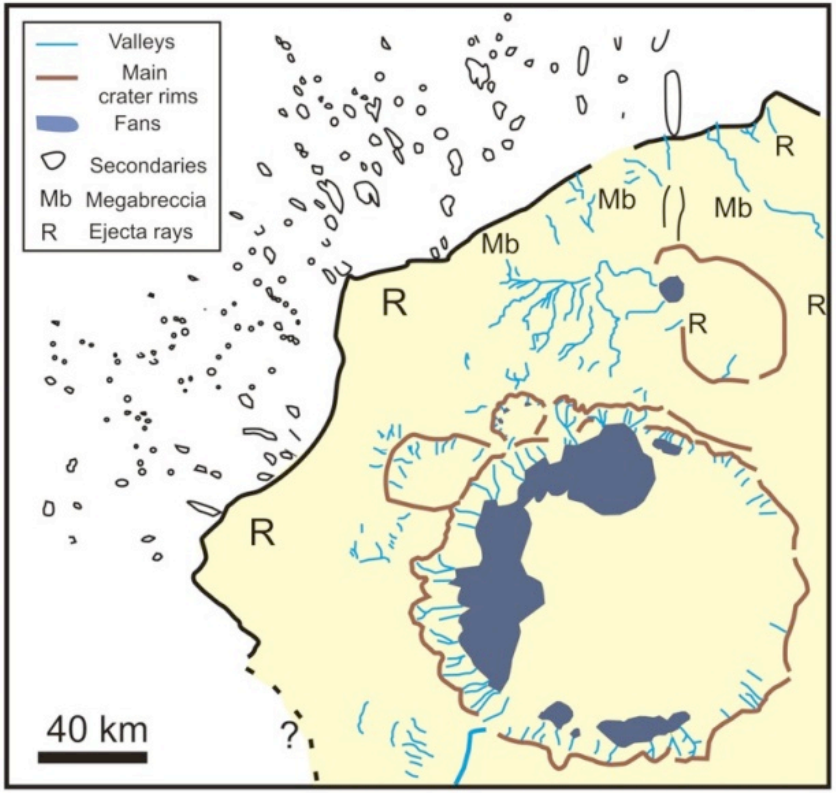



figure by Nicolas Mangold

- Eberswalde's delta postdates great majority of Mars aqueous minerals, fluvial activity, and up to 99% of degradation.

  → Potentially disconnected from early global wet interval? Long gaps between episodes are expected. (Assumptions: Gradual atmospheric loss, and rare orbital conditions required for melting).

- Work by Doug Jerolmack's group shows multiple lobes form from steady water and sediment input [e.g. *Kim and Jerolmack*, J. Geol 2008]

  → Did the main delta switched on once, operated for some time, then shut down for 2+ billion years?

# Constraints: hydrology

- Runoff required scales with delta volume.
  - 5+/-1 $km^3$ delta volume
- Lifetime, $>10^3$ years: Evaporation constraint, assuming single-phase of flow [*Irwin*]
  - $\Delta t_{Ebers} > 10^2$ yrs, most likely $\Delta t_{Ebers} > 10^{3\text{-}4}$ years.
- Peak discharge ~ 500 $m^3/s$: (meanders, boulders, inlet geometry) [*Irwin, Howard, Moore, Dietrich …*]
  - $Q_{max} > 100\ m^3/s$ (boulders; meanders; inlet geometry)
- Inference: Interspersed high and low flow, not monotonically declining [*Irwin*]

# Coupling impact energy to fluvial activity

*Preexisting aquifer released by impact:*

1. Liquefaction triggered by seismic shaking
2. Impact fractures cryosphere
3. Rim topography creates hydraulic head

*Liquid water generated by impact:*

4. Shock melting of preexisting ice
5. Ejecta melts preexisting ground ice [*Mangold*, LPSC 2011]
6. Ejecta melts preexisting snowpack
7. Ejecta contains water which melts after landing
8. Holden crater is a vapor source, resulting snow melts on contact with ejecta
9. Holden crater is a vapor source, resulting snow melted by sunlight [*Kite, Michaels, Rafkin, et al*., JGR, in press]
10. Localized greenhouse sustained by vapor release [*Colaprete & Segura*, LPSC, 2009]

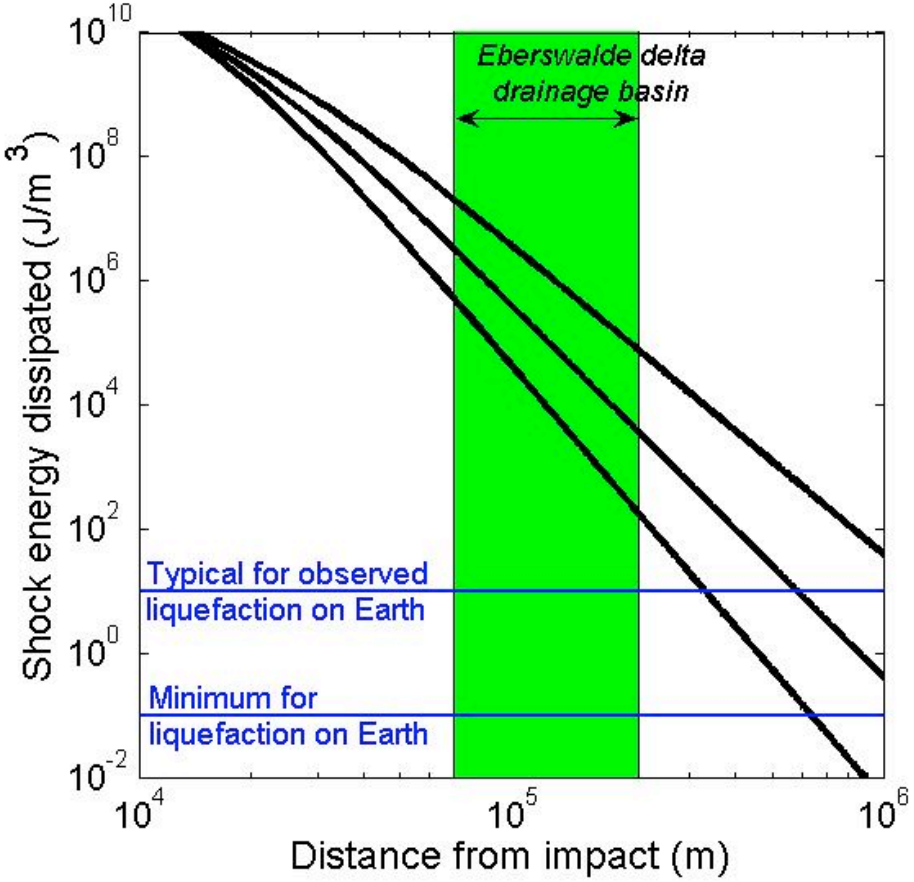
# Groundwater release?

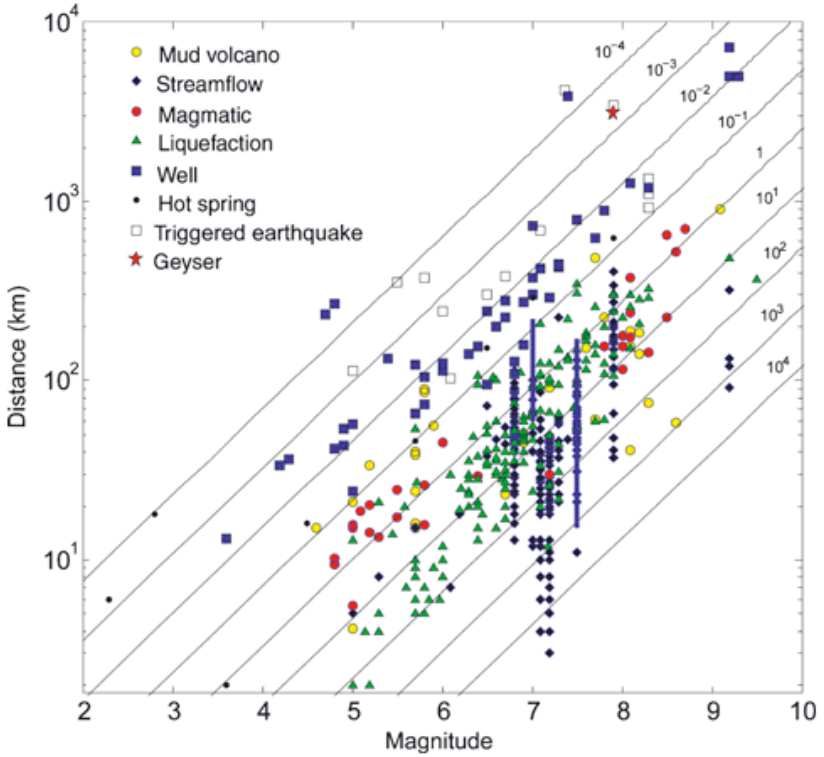
**Fracturing the cryosphere?**

[*Wang & Manga*, Icarus, 2005]

**Liquefaction?**

e.g. [*Harrison et al.*, GRL, 2010]



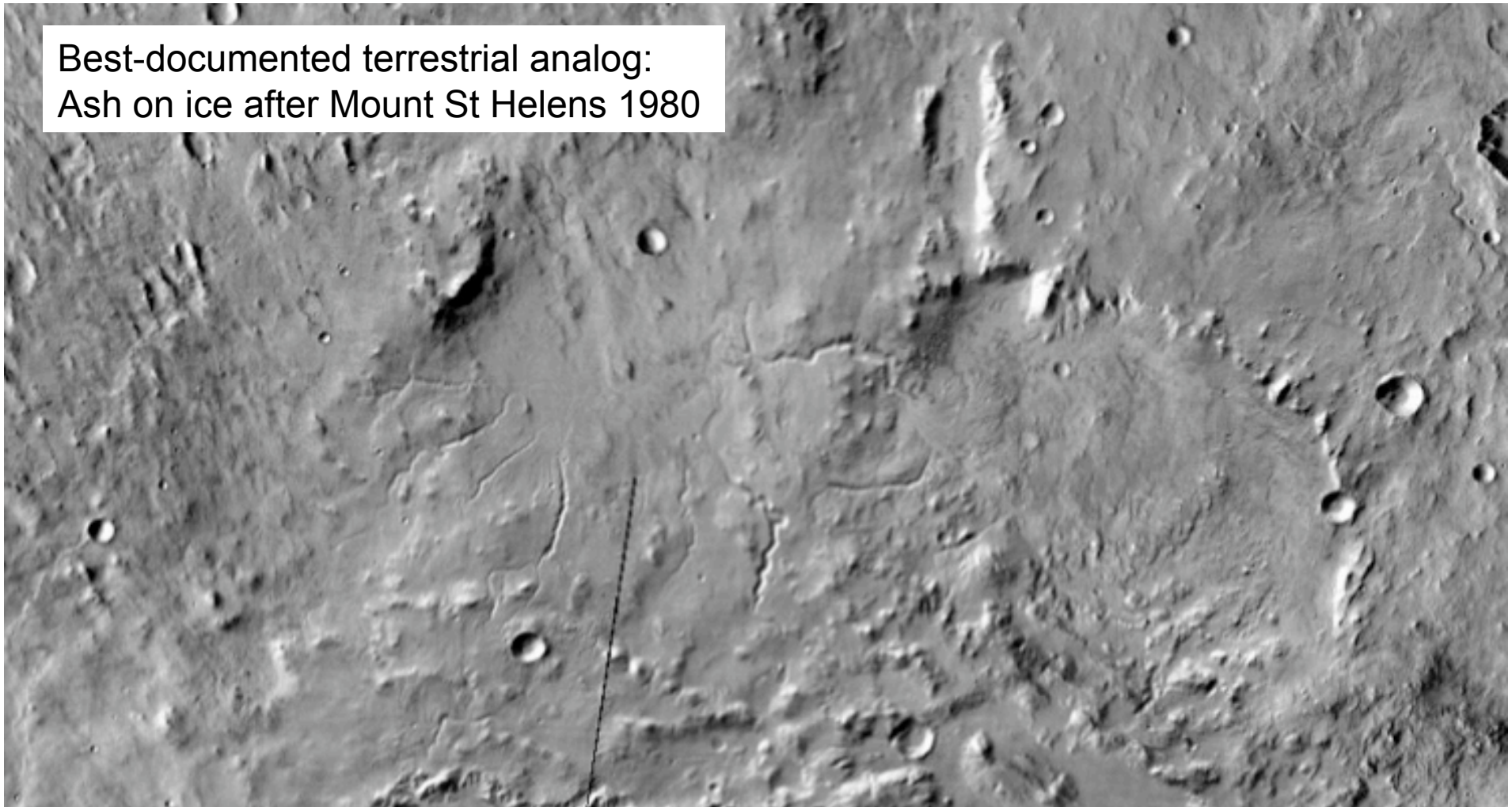



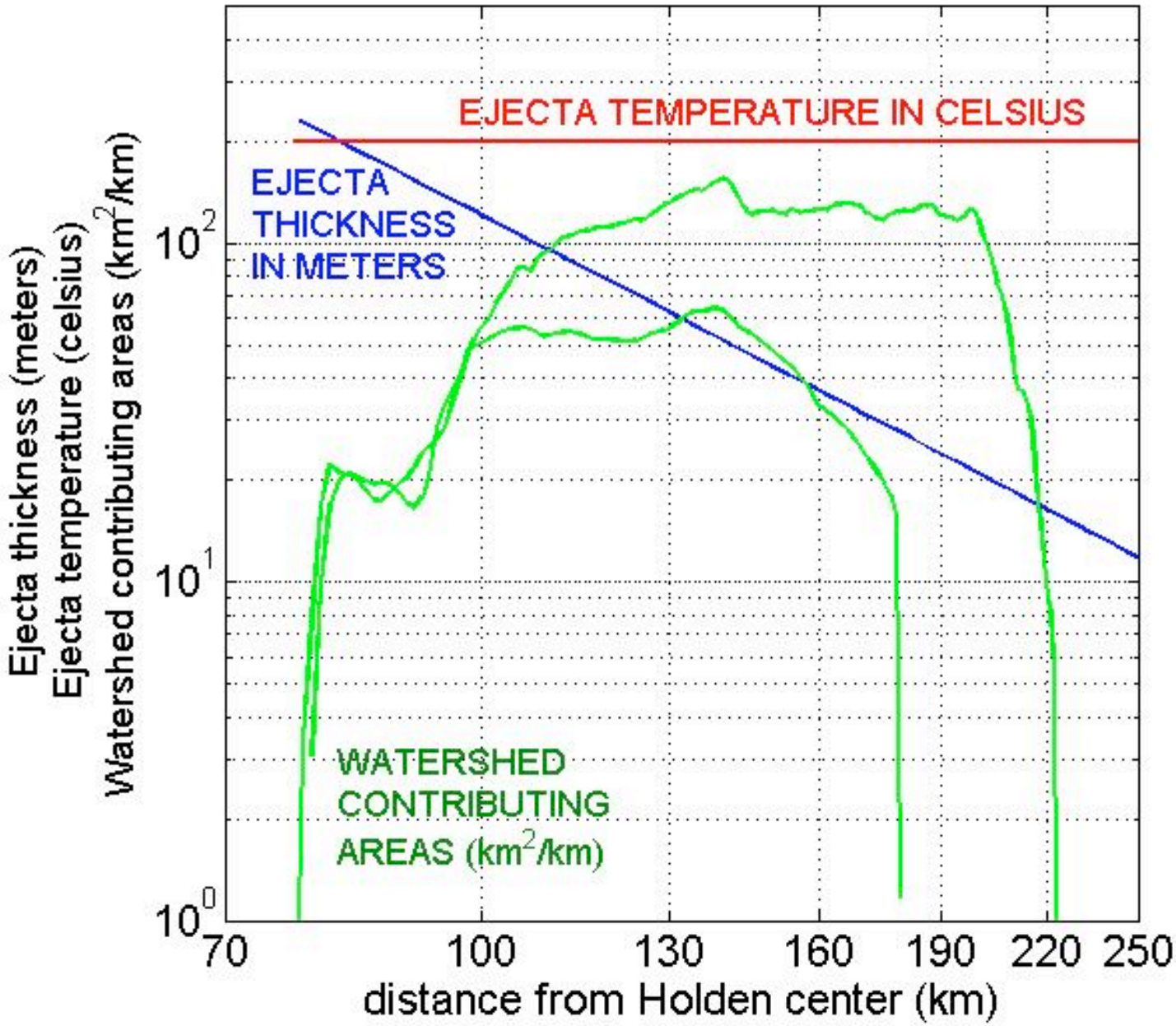

[*Wang & Manga*, Geofluids, 2010]

Parameters from [*Barnhart et al.,* 2010; *Barnhart & Nimmo*, 2011]

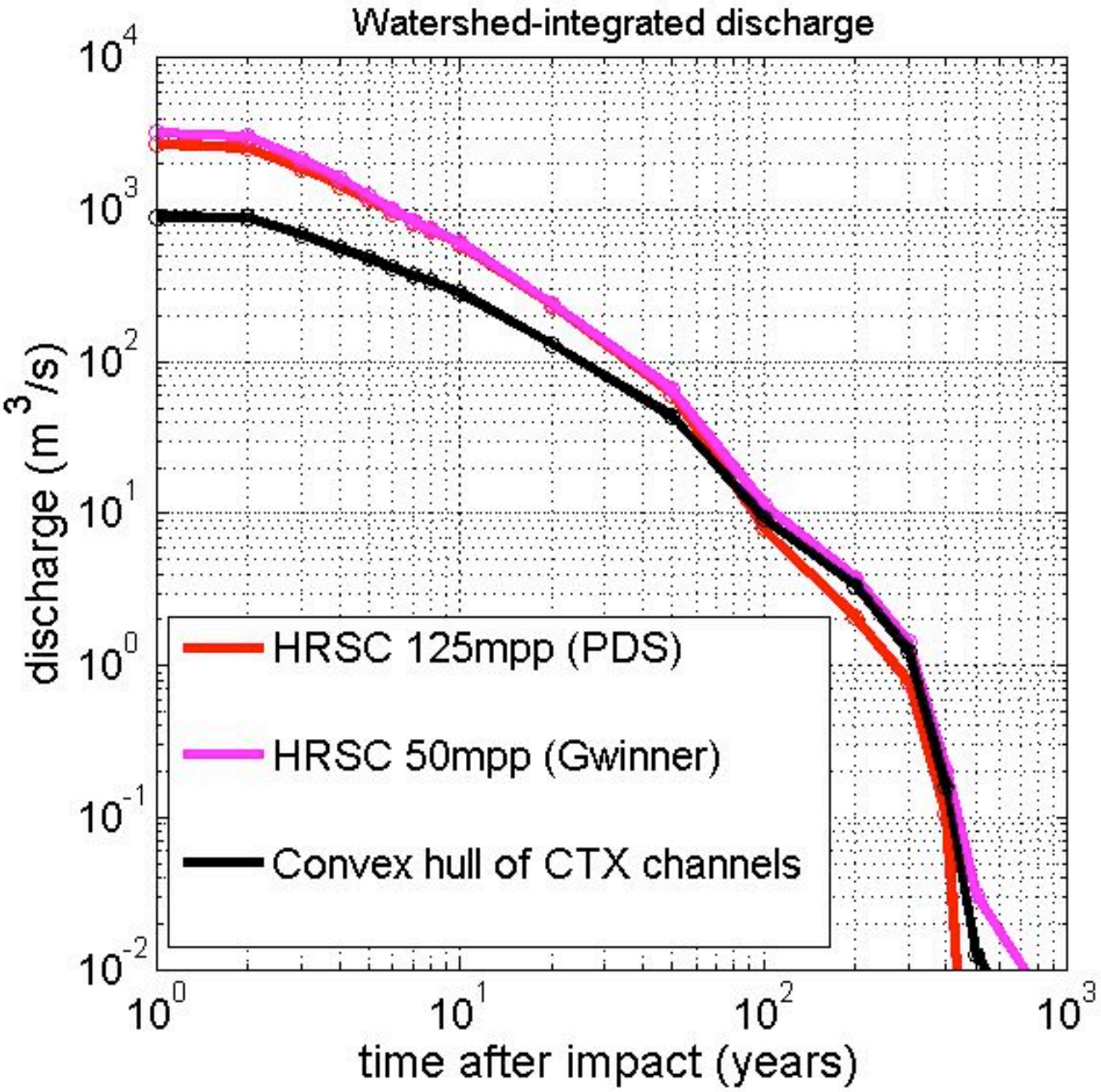
## Ejecta melts preexisting snowpack

1. Rayleigh-Z model [e.g., *Barnhart & Nimmo,* 2011] predicts axisymmetric *T* and *h* of ejecta.
2. 1D column code solves Stefan problem $Q_w$ = f(*T*,*h*,*S:W*,*t*); unlimited snow supply is assumed (which is reasonable).
3. Integrate over watershed(s).



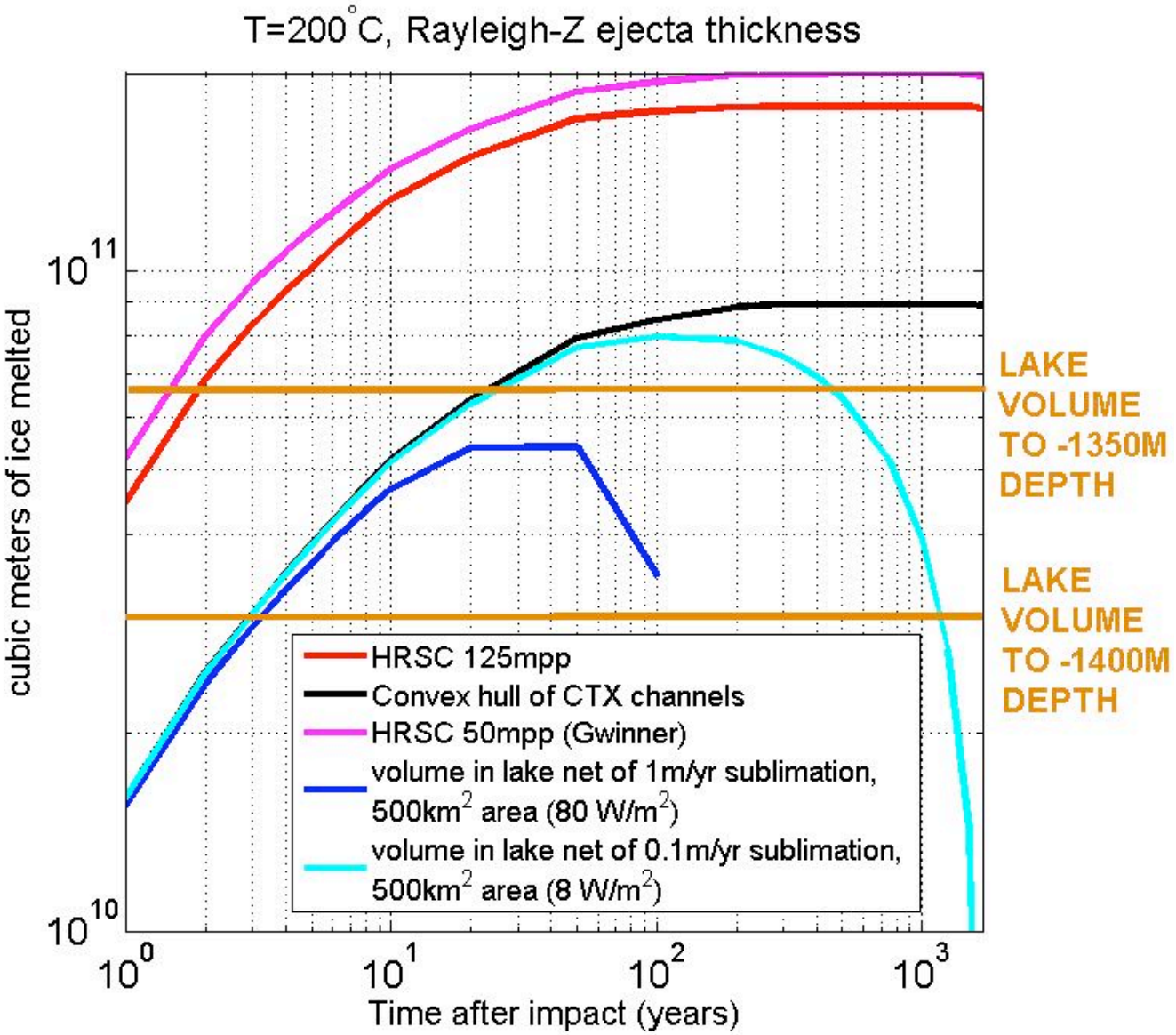

EJECTA TEMPERATURE IN CELSIUS
EJECTA
THICKNESS
IN METERS
WATERSHED
CONTRIBUTING
AREAS (km²/km)
Ejecta thickness (meters)
Ejecta temperature (celsius)
Watershed contributing areas (km²/km)
10²
10¹
10⁰
70
100
130
160
190
220
250
distance from Holden center (km)

$Z = 2.71$




*T* = 200C (fixed)
*h* from *Z* = 2.71
*W:S* ratio 20:1
(for thermal model)

# How much water can be delivered without overfilling Eberswalde?




Implied volume-averaged water:sediment ratio of delta-building flows: ~16.

Generic problem for impact ejecta energy: find sinks for the first, rapid flood discharge.

# Summary

- No impact scenario that matches all the constraints has been found.
  - The key problem is generating late pulses of high flow (or suppressing the early pulse of high discharge).
  - Runoff from ejecta-on-ice can be modulated by regrowing ice layer – power spectrum of breakout floods?
- No observation rules out the impact hypothesis.
  - An 18km diameter crater appears to have on the Holden rim after the Holden impact, but before the Holden bajada. However, the HRSC 50mpp DTM indicates it's proximal ejecta does not intersect the Eberswalde delta catchment.
  - Population of small craters crosscut by channels could be due to postdelta channel widening.
- MSL can test the impact hypothesis.

# Impact hypothesis: tests and test locations


**1) First lake sediments should be in contact with hot ejecta.**

- Low-temperature hydrothermal minerals? Two phases of hydrothermal activity, possibly.


**2) Fluvially transported materials should be compositionally immature.**

- Rapid advance of physical erosion should outpace chemical weathering in cold environment similar to today's Mars. (analogy: subglacial environments on Earth)


**3) Delta deposition should be continuous.**

- Within the delta (and lakebeds, if any), there should be little to no paleosol development nor downward mobilization of elements (exceptions: top of delta, and present-day erosion surface)


**4) Holden ejecta deposits should pass continuously into base of delta.**

- Base of delta should include debris flows; overall fining-up trend


**5) Varves (or quasiperiodic layers in general) would disfavor impact hypothesis.**

Energy for runoff is derived from ejecta, not sunlight, so expect weak to no annual cyclicity. Threshhold processes → power-law distributions.


**6) Fining-up, with coarse clasts at the base.**

- Large sediment content in early flows; possibly mudflows.

– *Auxiliary stratigraphic prediction: Late-stage activity sourced in the South should postdate activity sourced in the North.*

# Why is Eberswalde special?

- How many long-lived high-discharge fluvial systems would we expect during a cold-climate epoch?
  - *Need a big impact next to an ice sheet.*
- 10-20 craters of the right size 3.5 Ga – 3.0 Ga.
- 3-6 visible impacts during high obliquity times
- Pedestal height (Kadish et al., 2010) suggests 17-38% of planet covered by ice.

  →*0.5-2.3 Eberswaldes are predicted (present-day surface ice inventory).*